FLIGHT EVALUATION OF A TIME-BASED AIRBORNE INTER-ARRIVAL SPACING TOOL

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Abstract

An airborne tool has been developed based on the concept of an aircraft maintaining a time-based spacing interval from the preceding aircraft. The Advanced Terminal Area Approach Spacing (ATAAS) tool uses Automatic Dependent Surveillance-Broadcast (ADS-B) data to compute speed commands for the ATAAS-equipped aircraft to maintain a required time interval behind another aircraft. The tool was evaluated in an operational environment at the Chicago O'Hare International Airport and in the surrounding terminal area. Three aircraft participated in the flights: a Piper Chieftain, a Sabreliner, and a Boeing 757. The Chieftain functioned as lead aircraft on which the Sabreliner spaced, and the Sabreliner served as lead for the B757. The implementation of the ATAAS spacing tool onboard the B757 included speed management through the autothrottles. Both manual and autothrottle speed management were included in the scenarios. Two basic types of scenarios, differentiated by the type of lateral navigation used, were flown: an "area navigation" (RNAV) based path which transitioned onto the final approach course, and vector scenarios in which headings were assigned to the first aircraft in the sequence. In these latter scenarios, the other two "spacing " aircraft would follow the lateral path of the first, using an onboard display of that aircraft's path generated by the ATAAS algorithm. Data collected consisted primarily of aircraft state data, algorithm outputs, and pilot subjective comments. All flight crews were research pilots. During the course of the flights, the aircraft were exposed to varying wind conditions, occasional firmware problems and other challenges. Results on the delivery precision of the algorithm, based on a target spacing of 90 seconds were as follows. For all scenarios a mean of 90.8 seconds with a standard deviation of 7.7 seconds was achieved. For the RNAV and vector cases respectively, M=89.3, SD=4.9 and M=91.7, SD=9.0 were achieved.

Introduction and Background

In recent years, air travel has increased at unprecedented rates, leading to traffic congestion in many of the nation's busiest terminal areas. With this trend expected to continue into the foreseeable future, many government and industry efforts have been focused on research programs aimed at alleviating congestion through development of procedures for airborne and ground-based use with supporting new technologies. To address this problem, the National Aeronautics and Space Administration's (NASA) Advanced Air Transportation Technologies (AATT) Project developed the concept of Distributed Air/Ground Air Traffic Management (DAG-TM). The DAG-TM concept involves various levels of collaboration between airborne and ground-based resources to enable less-restricted and more efficient aircraft trajectories throughout all phases of flight, leading to increased airport capacity[1].

One of the goals for capacity enhancements in the terminal area is to safely reduce the excess spacing that occurs in traffic streams. That requires the use of more accurate means of controlling the spacing intervals between arriving aircraft. One element of the DAG-TM concept focuses on terminal area operations and requires the development of procedures and technologies that allow aircraft to have more flexibility in choosing an efficient route through the terminal area while arriving at the runway threshold properly spaced from the preceding aircraft[2].

Previous research has investigated the feasibility of using traffic information displayed on the flight deck to enable airborne-managed spacing [3-6]. Simulator experiments conducted at NASA Langley Research Center (LaRC) involving the use of Cockpit Display of Traffic Information (CDTI), including a display of the lead traffic's location and other predictors on the subject aircraft's Navigation Display (ND), found that time-based spacing was the most useful technique. A "time box" was used to represent the position where the subject aircraft ("ownship") should be, and provided a position target for the ownship to achieve to be at the correct spacing interval behind the aircraft it was following. The spacing interval was assigned by Air Traffic Control (ATC). The studies concluded that this concept was feasible from a crew workload and acceptability standpoint. Accurate knowledge of the positions and speeds of the aircraft with fast data update rates are necessary. Recent improvements in display and computing capabilities and broadcast of traffic state data make the concept realizable.

An airborne tool was recently developed at LaRC based on this work, refining the technique to better meet the objectives of the Approach Spacing concept. The tool, called the Advanced Terminal Area Approach Spacing (ATAAS) tool, is based on the concept of an aircraft maintaining a time-based, rather than distance-based, spacing interval from the preceding aircraft[7]. The ATAAS tool uses Automatic Dependent Surveillance-Broadcast (ADS-B) aircraft state data along with final approach speeds and wind data to compute speed commands for the ATAAS-equipped aircraft to maintain the required time interval behind the other aircraft. This tool has undergone extensive Monte Carlo analysis to characterize and refine its performance. Although the tool has many potential applications in different types of operational scenarios, including en-route and oceanic operations, the concept of in-trail spacing in the terminal area (i.e., aircraft are spacing longitudinally while following directly behind each other) was the logical first step in the evolution of the end-state goal of more efficient and flexible maneuvering through the terminal area.

To evaluate the in-trail spacing tool and associated procedures, a piloted simulation was conducted to assess pilot workload and acceptability of the approach spacing concept[8]. Results showed that the aircraft was able to consistently achieve the target spacing interval within one second (the equivalent of approximately 220 ft at a final approach speed of 130 kt) when the ATAAS speed guidance was autothrottle-coupled, and a slightly greater (4-5 seconds), but consistent interval with the pilot-controlled speed modes. The subject pilots generally rated the workload level with the ATAAS procedure as similar to that with standard procedures and also rated most aspects of the procedure highly acceptable. Positive results were received from subjective and eye-tracking data used to measure heads-down time. The ATAAS flight evaluation documented in this paper was a follow-on to the simulator study.

Part of the concept vision is the ability for un-equipped aircraft (i.e., those without an ATAAS implementation) to also participate in this operation by means of a charted arrival. Including the nominal routing and speed profile as part of the charted arrival allows an aircraft that can maintain the charted profile to be cleared for and fly this arrival. By broadcasting its position and the appropriate data, it can also serve as a lead aircraft for the ATAAS-equipped aircraft sequenced behind it. This concept can also be extended to lower-density facilities as their traffic levels increase. The procedure allows aircraft to perform approach spacing operations at those facilities, enabling more consistent and reliable spacing of arrivals with minimal changes to infrastructure.

A fundamental issue that is unchanged from current-day procedures is the responsibility for maintaining separation between aircraft. Under the new scenario, that responsibility remains with the Air Traffic Service Provider (ATSP). To assist the controller in fulfilling this role, ground tools have been developed based on anticipated information requirements.

The ultimate goal behind the in-trail concept is not to optimize precision spacing for individual pairs of aircraft, but rather to achieve a system-wide improvement in performance. That improvement will be realized by obtaining better consistency in spacing from a system-wide standpoint, sometimes at the expense of having excessive spacing between individual aircraft pairs. As such, no single aircraft will be given guidance to aggressively achieve a spacing interval beyond what would normally be expected in current-day operations. It is readily apparent that increasing the speed of one aircraft excessively in order to "close up the gap" with a preceding aircraft would quickly destabilize the system and would not, in fact, increase system-wide performance. In addition, this destabilization could multiply the effect on the speed required of every aircraft that is in-trail, creating increasingly larger gaps and speeds well beyond acceptable levels by today's standards. In order to enforce this ideal, realistic limits were placed on the speed guidance provided by the ATAAS system. Thus, the commanded speed will not exceed 10% of the nominal (charted) speed for any given segment on the arrival. In future applications, the reduction in system throughput that could result from this type of limitation could be recovered through other methods, such as adjusting the lateral route in a designated maneuvering area. Flight crew procedures were developed to implement this in-trail concept with a focus on minimal impact to current workload levels.

Only a subset of these procedures were used in the flight evaluation, since only one member of the flight crews was performing the ATAAS task. The other pilot performed safety pilot duties. Supporting display elements provided information on the mode of operation and the state of the ATAAS-equipped aircraft ("ownship") relative to the aircraft it was spacing behind (the "lead" aircraft). A trail of "history dots" behind the lead aircraft show its ground track on the ownship's ND, and can be used for lateral navigation. A simple pilot interface with the ATAAS tool was provided for the selection of the lead aircraft and to enter other appropriate data. To evaluate the ATAAS spacing tool and provide a comparison with Monte Carlo analysis and simulator data, several types of scenarios were tested in an operational environment.

ATAAS Interface

EADI Display

Output from the ATAAS system was shown in various locations and forms on the pilots' displays. Pilots obtained ATAAS guidance from these displays, and additional status data from the Flight Management Computer (FMC)-Control Display Unit (CDU) pages (described below). The ATAAS symbology on both Electronic Attitude Director Indicator (EADI) and ND appeared only after a lead aircraft and spacing interval were selected from the CDU page.

The EADI used for this flight evaluation was the standard B757 EADI, very similar to those currently in use in most aircraft of this type (Figure 1). It includes a Fast/Slow (F/S) indicator on the left side of the display, which normally is tied to the speed mode in use. For example, when the crew is flying the aircraft in "Speed" mode (meaning speed is controlled by dialing the target speed into the Mode Control Panel (MCP) Speed window), the red "speed bug" on the airspeed indicator moves to the target speed displayed in the window, and the F/S indicator reflects the relationship of the current aircraft speed with the target speed. If the current speed is faster than the target speed in the MCP window, the pointer on the F/S indicator moves towards the "F"; if the current speed is slower than the MCP window speed, the pointer moves towards the "S".

The ATAAS implementation on the EADI (Figure 2) made use of the F/S indicator to reflect the relationship between the current aircraft speed and the electromechanical airspeed indicator also tracked the ATAAS speed guidance, giving the pilots another reference. In addition, the commanded speed appeared in digital form on the F/S indicator, in green font. The displayed readout, the pointer on the F/S Indicator, and the bug on the airspeed indicator all followed the commanded speed from the ATAAS algorithm.

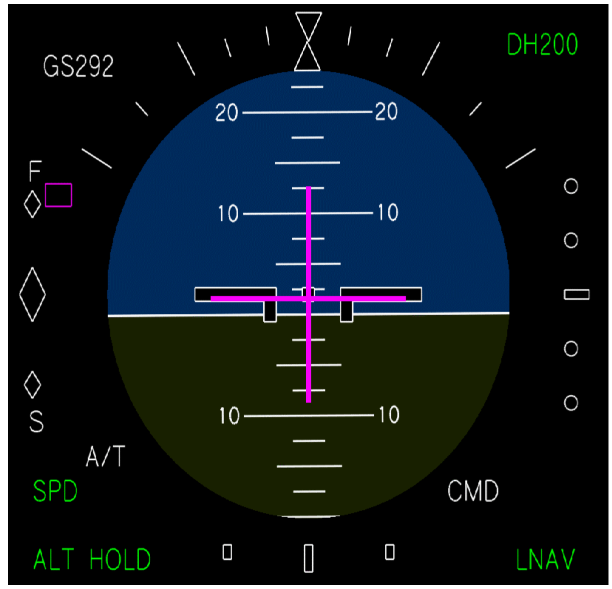

Figure 1. EADI with Normal Symbology

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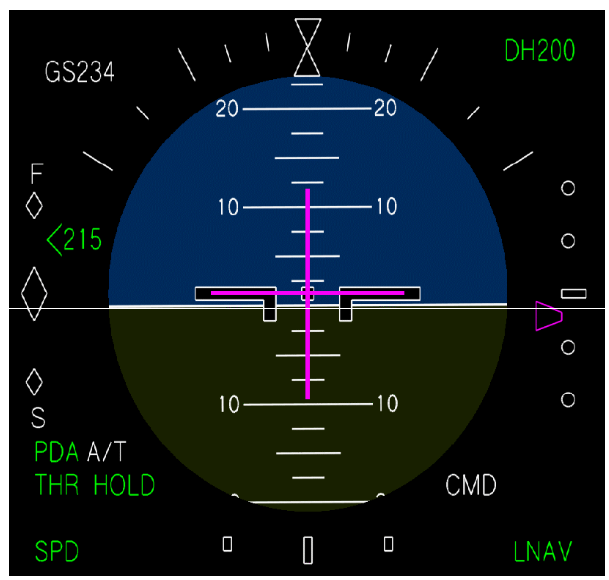

Figure 2. EADI with ATAAS Symbology

A feature of the ATAAS algorithm is its ability to provide a smooth transition from the commanded speed required for achieving the spacing interval, to the final approach speed entered on the ATAAS Approach Data CDU page. The algorithm is automatically switched to this approach mode near the final approach fix to allow enough time to achieve a stabilized final approach. When the algorithm transitions to this mode, it is no longer actively "spacing" on the lead aircraft, and an "APPR" message is provided above the F/S indicator to inform the pilot of the change.

Navigation Display

Symbology added to the ND provided additional information on the ATAAS guidance and aircraft spacing status (Figure 3). Three main pieces of information were provided: 1) a data block that included currently entered ATAAS data and lead aircraft range, 2) a spacing position indicator, and 3) lead aircraft highlighting and position history dots.

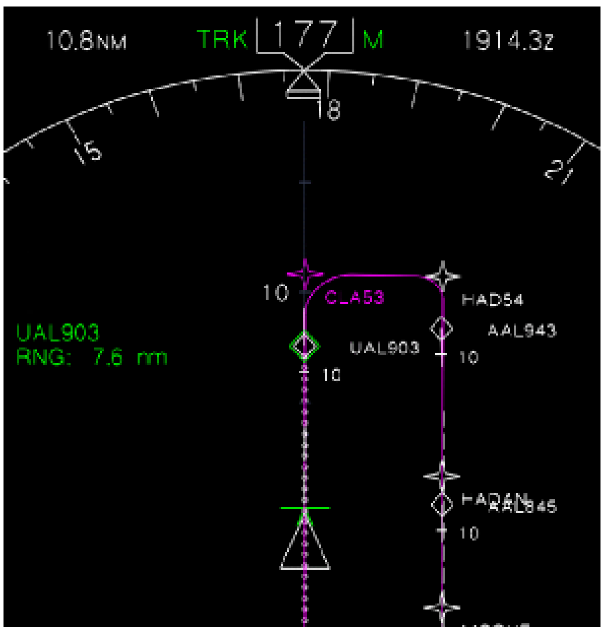

Figure 3. ND with ATAAS Symbology

The data block showed the call sign of the lead aircraft (the aircraft selected on the CDU page) and the current distance in nmi to the lead aircraft. The data block was updated as the distance between the aircraft changed and to reflect other changes (e.g., new lead aircraft selection).

A spacing position indicator was provided to show the position where the ownship should be in order to achieve the proper spacing interval (based on the currently entered lead aircraft and desired spacing interval). This indicator consisted of a short green line perpendicular to the ownship's ground track, with an inverted "V" attached to the midpoint of the line. When the ownship was properly spaced, the spacing position indicator fit exactly over the apex of the white triangular ownship symbol. If the spacing position indicator was behind the apex of the ownship symbol, the ownship was ahead of where it should be (actual spacing interval was less than the targeted interval). Conversely, if the spacing position indicator was ahead of the ownship symbol, then the ownship was behind where it should be (actual spacing interval was greater than the targeted interval). This indicator provided a visual reference of the ownship's position relative to the desired spacing interval.

The position history dots showed the ground track of the currently selected lead aircraft. This history trail feature allows an ATAAS-equipped aircraft to maintain spacing behind an aircraft that is not on an RNAV route, such as one that is being radar-vectored or on a visual approach, by following its history dots.

FMC-CDU pages

Flight crew interface with the ATAAS system was accomplished through customized FMC-CDU pages, accessed through a function key on the CDU, which was labeled "ATC". Inputs to the custom CDU pages were the selection of traffic-to-follow, spacing interval, winds, and final approach speed of ownship and lead aircraft. Since one of the pilots was required to perform the role of safety pilot, inputs to the CDU were accomplished by a researcher situated on the flight deck.

Test Environment and Conditions

Participating Aircraft and Onboard Equipment

Three aircraft participated in the ATAAS flight evaluation, and represented performance characteristics of a high-performance general aviation aircraft, an executive jet-type aircraft, and a transport category aircraft. The aircraft were a Piper Chieftain (Aviation, Navigation, Satellite Programs, Inc.) a Sabreliner (Rockwell Collins), and a Boeing 757 (NASA's Airborne Research Integrated Experiments System – ARIES). The sequence of aircraft remained the same on the all scenarios: the Chieftain was first, followed by the Sabreliner, and ARIES last. Two-aircraft sequences were flown when either of the first two aircraft was grounded for refueling or maintenance. Two levels of onboard equipment were used for this flight activity: broadcast-only and spacing-capable. Since the role of the Chieftain was to act solely as a lead aircraft, it was only required to broadcast aircraft state information. Equipment required for this task is a Mode-S transponder (broadcasting the basic ADS-B message) and a GPS receiver. Both the Sabreliner and the B757 required capabilities that allowed them to space on "leading" aircraft. In addition to the Mode-S transponder and GPS receiver, this also required an ADS-B receiver unit and the spacing algorithm.

Flight Crews

All four flight crew members flying the spacing tools (the Sabreliner and ARIES crews) were experienced pilots. One was a former airline pilot, two formerly flew transport category cargo aircraft and the fourth is an experienced research test pilot. No subject pilots were used in the ATAAS flight activity. The pilots were given presentations on the Approach Spacing concept and the spacing tool, as well as training time in the simulator as needed to develop proficiency on the scenarios.

Flight Environment

The flight activity was conducted at the Chicago O'Hare International Airport and surrounding terminal airspace. The ATAAS flight participants flew paths representative of those normally flown by arrival aircraft. In order to not adversely affect itinerate traffic, the flights were conducted at night. As this was an operational environment, the assignment of runways and direction of traffic patterns (left or right) was subject to change with minimal notice. It was anticipated that any of seven runways with either left or right traffic patterns could be assigned. Area Navigation or "RNAV" routes were developed to accommodate any of these possibilities. Conducting the flights in an operational environment presented several challenges not encountered in simulation. One of the three aircraft was limited to operations in VMC conditions such that a lower altitude than that used for the other two aircraft was sometimes required. The effect was to have aircraft subject to wind fields that, at times, were significantly different. A second challenge was responding to errors in the ADS-B link, which occasionally transmitted erroneous groundspeed data to the ATAAS algorithm. This required modification of the onboard processing to include additional filtering. The filtering was designed to minimize the effect of the erroneous data on the algorithm, which would have resulted in inappropriate speed commands. Finally, due to traffic conditions, several runs were conducted in which a significant tailwind was present on final approach. Although the algorithm had been tested in simulation with winds, the effect of the type of winds encountered in flight were not previously studied. Air traffic control services were provided by Chicago Tower and Approach Control. As this was not an evaluation of procedures, the tasks for the controller were (1) to provide control instructions that would position the aircraft for the start of each run and (2) in the case of the vector scenarios, to provide vectors and speeds as appropriate. In positioning aircraft for the start of each scenario, the controllers did not employ a greater degree of precision than they normally would in day-to-day operations. No special accommodations were made to provide other than normal services.

Scenarios

Two basic types of scenarios were flown: an RNAV path that represented a pre-defined lateral route and a vector path scenario. Two variations of the vector scenario were flown, a nominal (downwind-base-leg routing) and a "weather" case representative of an aircraft being vectored around weather on the downwind leg. Figure 4 depicts a generic plan view of the basic routes flown. Note that in the case of the nominal vectors, the controller would provide vectors intended to basically overlay the RNAV route. To begin a scenario, the controller would provide vectors to establish the aircraft on the "inbound leg" (this simulated aircraft entering the terminal area). Altitudes for initiation of the scenarios varied between 5000' and 7000' depending on other traffic. The initial speeds were 200 knots indicated airspeed (KIAS) for the Chieftain and 210 KIAS for both the Sabreliner and ARIES . The spacing between each pair of aircraft was approximately six miles; the controller was asked to provide reasonable spacing, but not to a greater degree of precision than would normally be expected in day-to-day operations. As aircraft #2 and #3 in the sequence were established, they were to assume that an Approach Spacing clearance was issued and to follow ATAAS guidance cues accordingly.

RNAV Scenario. All participating aircraft flew the RNAV route through the transition onto the final approach course. Fourteen RNAV paths were developed to accommodate any one of seven runway assignments, left or right traffic. The Chieftain would decelerate to 170 KIAS at the turn to base leg, as charted. The following aircraft would follow their respective speed cues.

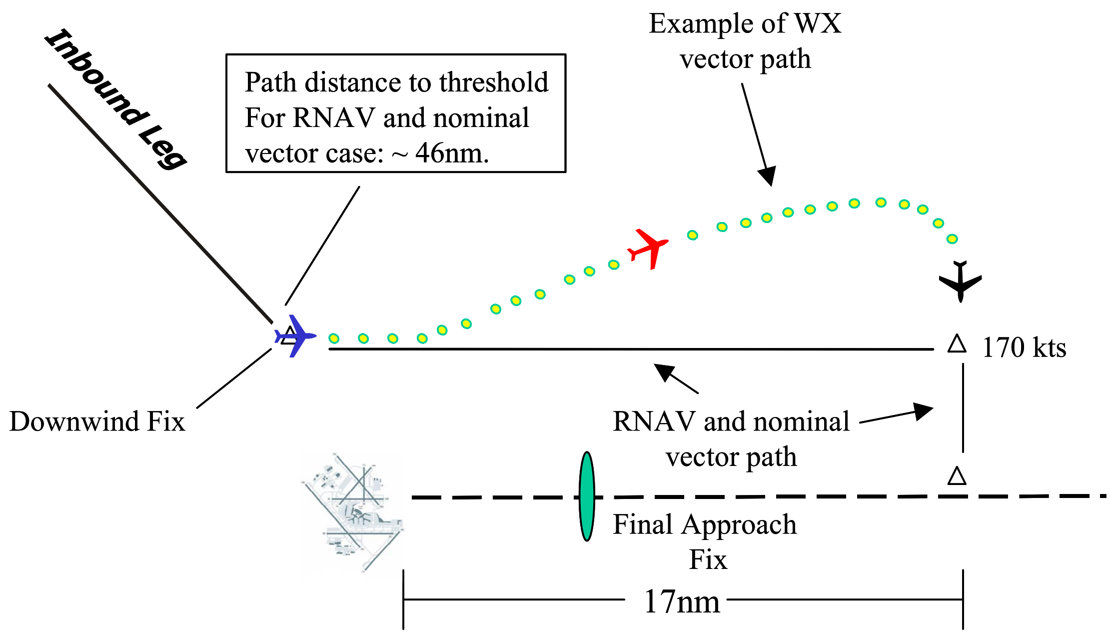

Figure 4. ATAAS Flight Paths

Vector Scenarios. Upon intercept of the "inbound leg" the first aircraft would receive vectors from the controller for turns to downwind. In the nominal vectoring case, vectors were issued to the Chieftain that would approximate the RNAV path with a speed reduction issued at the downwind-to-base turn. The trailing aircraft would follow the lateral path of the aircraft ahead, as depicted on the ND, and the ATAAS speed guidance. The weather vector case differs in that the controller issued off-nominal route vectors to simulate the presence of a weather cell. It should be noted that weather was used only as one example of why the capability to follow the lateral path of a leading aircraft might also be useful. This type of "follow-the-leader" scenario might be useful during runway changes and in instances where delay absorption strategies may be required.

In all cases the aircraft would intercept and track the ILS to 200' AGL, where it would level off and maintain speed and track until crossing the threshold. At that point, a go-around and climb-out was initiated and aircraft were vectored into position for the next test run.

One additional variation on the scenario was used to demonstrate the ATAAS algorithm's flexibility in allowing the flight crew to change the lead aircraft on which they were spacing. This scenario began with twice the normal interval between two of the aircraft to allow for a third aircraft to be merged in between them. The controller would vector the first two aircraft (Chieftain and ARIES) to stage them with essentially twice the normal spacing, such that ARIES would maintain a spacing interval of 180 seconds. The Sabreliner would then be inserted between the two aircraft and begin spacing on the Chieftain at the nominal 90 seconds. ARIES would select the new lead (Sabreliner) and follow at the nominal 90 seconds.

ARIES Flight Deck Procedures

During climb-out to the assigned altitude, the aircraft designated as the traffic-to-follow (TTF) was selected on the CDU. This initiated the ATAAS algorithms and the accumulation of TTF position history data. The ownship final-approach speed (verified with the safety pilot), TTF approach speed, airport wind velocity, and minimum allowable ATAAS separation distance were then entered in the research CDU. After the flight path of ARIES was stabilized in-trail of the TTF on the in-bound leg, or no later than just after the turn onto the downwind leg, the safety pilot would request clearance to follow traffic from ATC. The desired spacing interval time was then entered to activate the ATAAS speed advisory mode. After concurrence among the cockpit crew that ATAAS was providing reasonable speed advisories, active speed guidance was initiated by engaging a designated push button switch on the Experimental Display Control Panel (EDCP), which is unique to ARIES. Subsequent control of airspeed was then relegated to the research pilot or to the autothrottles through the thrust management computer, depending on the test-matrix scenario, to maintain the ATAAS commanded speeds for the remainder of the approach. ATAAS speed guidance was deactivated on the EDCP and the TTF deselected after crossing the runway threshold in preparation for the next run. A similar set of procedures was completed onboard the Sabreliner to activate the ATAAS system and conduct the approach spacing operation, using Rockwell's particular implementation of the algorithm.

Scenario Run List

A listing and ordering of the runs was based on operational, rather than experimental, considerations. The target number of runs was seven per flight period (maximum of four hours). The list included 2 RNAV runs, two nominal vectoring runs, and two weather vectoring runs. For each type of run, ARIES would fly one pattern with manual throttles and the other with autothrottles. Finally, one "re-sequence" run scenario was included for each flight period. No attempt was made to counter-balance the runs.

Data Collection

Time-stamped latitude, longitude, altitude, ground speed, and ground track data for the three aircraft were recorded onboard ARIES. In addition, many other parameters relating to the mode of operation of the autoflight system were also recorded for ARIES. Recorded data from the ATAAS system included the state in which the system was operating, and the commanded speed, time interval, and distance between the ARIES and the lead aircraft, as well as numerous other parameters used for verification of system operation.

Limited subjective data were obtained by administering a verbal questionnaire to the pilots. Questions centered around the acceptability of the ATAAS tool, the acceptability of the amount of head-down time required for using the system, confidence in the guidance provided by ATAAS, and the pilot's comfort level in using the tool. Each of the four questions was rated on a 1-7 scale.

Results

The results presented are, with a few noted exceptions, from the ARIES aircraft. Performance data for the Sabreliner has not been fully analyzed and will be included in a subsequent, more detailed report.
In considering the results of the flight evaluation, recall that a single pilot was performing the ATAAS flight related tasks, a researcher assisted with the CDU interactions, and that the performance monitoring functions envisioned for the pilot not flying were not performed because of safety pilot duties.

Delivery precision at the runway threshold, although not as precise as demonstrated in the simulator study, were still generally good**.** The inter-arrival times are provided in Table 1 for 28 data-collection flight segments (11 RNAV and 17 vector scenarios).

Table 1. Runway Threshold Crossing Times

	Mean	Standard Deviation
RNAV Case	89.3	4.9
Vector Cases	91.7	9.0
All Cases	90.8	7.7

The following factors adversely affected runway delivery times. A filter was incorporated into the algorithm to address an ADS-B firmware problem that would not be present in a production system. Due to very large wind changes on final approach, this filter would sometimes mask the wind change, with the resulting spacing intervals being off from the nominal interval. It is reasonable to say that in an operational system, these shortcomings with the firmware would be resolved; and therefore, this particular filtering in the algorithm would not be required. Secondly, actual aircraft deceleration that varied from the ATAAS generated deceleration schedule also resulted in delivery errors. Additional training and parameter tuning may address this problem.

In general, the spacing algorithm performed well when not artificially constrained by additional filtering. Of particular note is the performance of the algorithm in response to changes in wind velocity. Surface winds were received from the Automatic Terminal Information System (ATIS) broadcast. Several cases were noted where a shift in wind direction of greater than 180 degrees (with speeds of 10 to 25 knots) occurred while ARIES was on final. Inter-arrival spacing times for three of the four cases, in which wind shifts of greater than 180 deg occurred on final, were within 4 seconds of the goal time of 90 sec. Figures 5 and 6 show data for a run in which a wind shift in excess of 230 deg was encountered. Figure 5 shows the wind and Figure 6 shows commanded vs. actual airspeed. The data shown represent the last ten minutes (approximately 25 nm) of the approach. For perspective, this approach was conducted to Runway 4R and the wind shift occurred shortly before the turn onto final approach. Note that in the wind data shown in Figure 5, the scale for wind direction is located on the left and the scale for magnitude is on the right. (The scaling unit values were selected for compatibility.) The vertical line in the middle of the wind direction indicates a shift through 360 degrees true North.

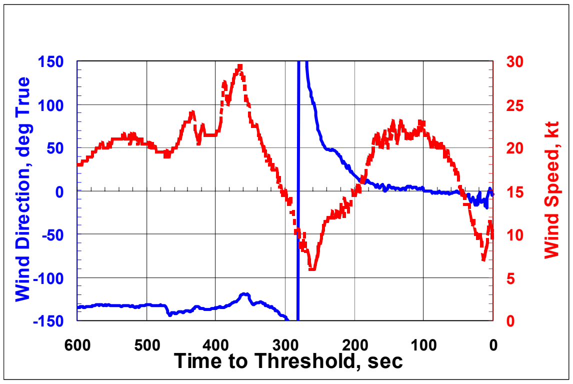

Figure 5. Wind Velocity for scenario with greater than 230 deg. wind shift.

Figure 6 shows the airspeed tracking performance (with autothrottles coupled) verses ATAAS commanded speeds. For the vectoring scenarios, the pilots of the aircraft using the ATAAS guidance were required to track the lateral path of the aircraft ahead. Although quantitative data is not available, tracking performance of the lateral path was generally good for both the Sabreliner and ARIES.

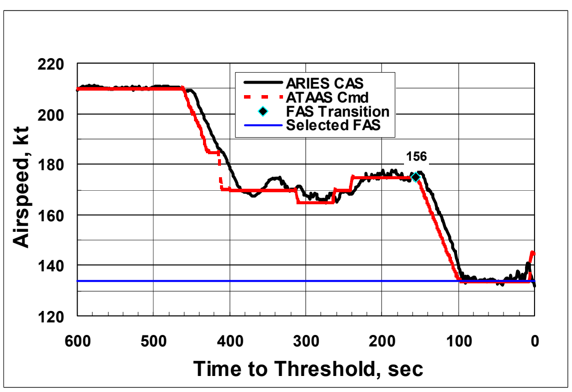

Figure 6. Airspeed Tracking Plot

Figure 7 is an example of the actual tracks of two aircraft for a weather vector scenario. The lead aircraft was provided vectors from the controller and the following aircraft was tracking the lateral path of the lead. One of the runs demonstrated the utility of displaying the ground track of the lead aircraft, even though all the aircraft were instructed to follow the RNAV lateral path. In that case, the lead aircraft overshot the turn to the final approach course, and the following aircraft followed its time history (instead of the RNAV path), thereby alleviating a potential loss of separation. In an operational system, this maneuver would have to be approved by ATC, but could be beneficial.

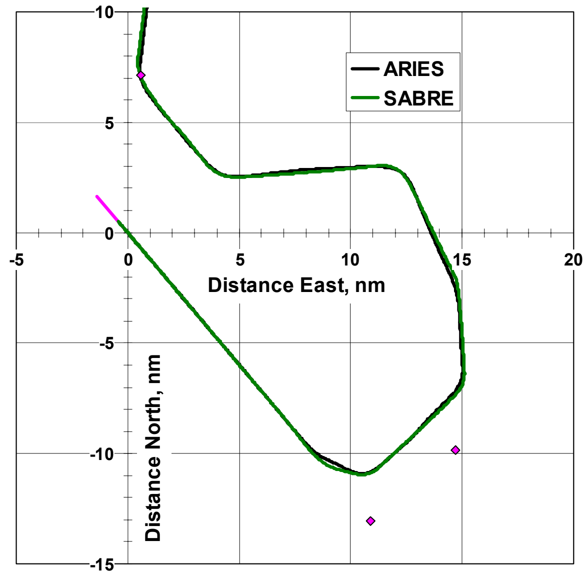

Figure 7. Flight paths of lead aircraft with following aircraft tracking the lead aircraft's lateral path (two-aircraft run)

For speed management, both manual throttle and autothrottle coupled cases were flown. Although there was no statistically significant difference between delivery precision for the two cases, it was noted that threshold crossing times were generally early when autothrottles were engaged and late when manual throttle control was used. The two research pilots that flew both cases stated that the workload was lower when autothrottles were engaged.

Research pilot comments were generally positive regarding the concept and the interface implementation for the flight activity. The pilots found that flying the ATAAS-generated speed commands was easily managed. Even with minimal exposure, pilots exhibited an understanding of the logic behind the algorithm and were able to anticipate generated speed commands. Several strong comments were made regarding the spacing position indicator ("inverted V" symbol) located on the ND, which represented the optimal position of the ownship to achieve the required spacing. Specifically, when ownship was ahead or behind the optimal position, there was an "overpowering" urge to take action to minimize the position difference immediately, even though the pilots realized that by following the ATAAS generated speed commands proper spacing would be achieved at some point along the path. Comments were also made regarding display clutter due to the additional symbology. However, this could be alleviated with filtering of other traffic. A rigorous human factors evaluation of the ATAAS displays would be required to address this and other issues. A full set of questionnaire data was not gathered due to the demands of conducting the test in an operational environment. The time window for eliciting responses from the pilot to the questionnaire was limited to that available from the completion of the low approach through positioning on the inbound leg. The short time available, weather, and other considerations resulted in only approximately 60% of the questionnaire data being gathered for both spacing aircraft. However, from the data gathered, all pilots provided responses indicating the following: the ATAAS tool was acceptable, the heads down time was acceptable, they were confident in the guidance provided, and they were comfortable using the tool.

Researchers flew onboard both of the spacing aircraft, and noted two main issues, based on observations of the pilots performing the spacing task:

- For pilots of both aircraft, it seemed as if a minimal amount of time was required to understand the basics of the ATAAS concept and spacing tool.
- Pilots attempted to apply compensation strategies when the actual spacing was off from the assigned interval shortly after the ATAAS system was activated, contrary to instructions to follow the ATAAS speeds. This supports pilot comments.

As previously noted, the role of ATC was solely to support positioning of the ATAAS flight participants and to provide vector and speed clearances consistent with scenario requirements. This objective was clearly achieved in all cases without any adverse effects on any of the results.

Based on the results of this flight activity, these recommendations are made for further improvements to the ATAAS tool and procedure:

- Addition of wind data to the ADS-B message to support better accuracy and consistency of the algorithm's performance for the following aircraft in the presence of changing winds.
- Conduct further evaluations to refine the ATAAS symbology and displays and assess the factors for misinterpreting the displayed information.

Concluding Remarks

A flight evaluation and demonstration of a tool developed to support the Approach Spacing concept was conducted at the Chicago O'Hare International Airport. The objective of the flight activity was to evaluate the ATAAS tool in an operational environment and to demonstrate various applications of the tool. Over 30 approaches were flown during five flying periods. The primary evaluation metric was delivery precision at the runway threshold. In general, delivery precision was good. However, expected improvements in areas mentioned in the previous section (e.g., reliability of the ADS-B data received by the algorithm and wind data) would improve performance.

Four research pilots flew the approaches for the flight evaluation. All pilots felt that the task of flying the ATAAS-generated speed guidance could be integrated into a pilot's normal duties. It was also noted that the task was easier with the use of auto throttles. Pilots also stated that the task of tracking the lateral path of the leading aircraft was manageable and could be integrated into normal flying duties.

Although not evaluated in this flight activity, it should be noted that use of the ATAAS tool could reduce the required number of voice communications. Unburdening the controller from issuing speed instructions, and in some cases, limiting the number of vectors required could reduce congestion on the voice channels.

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Key Words

Spacing	Time-based spacing
ADS-B	Inter-arrival

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Mr. Gary Lohr is a graduate of Embry-Riddle Aeronautical University. He has been involved in research activities at NASA Langley for 16 years, most notably in the areas of Air Traffic Flow Management, investigation of Controller Display Aids, and Data Link Applications. Recently, he has served as the technical team lead for the terminal area work under the Advanced Air Transportation Technologies (AATT) Project. He has worked as an air traffic controller for both the US Navy and Federal Aviation Administration with tower and approach control certifications.

Ms. Rosa Oseguera-Lohr earned a Bachelor of Science in Engineering from the University of Illinois at Chicago and a Master of Science in Aerospace Engineering from Texas A&M University. Since 1987 she has worked at NASA Langley Research Center as a research engineer, on various projects involving human-in-the-loop simulator and flight experiments, with emphasis on development of procedures and technologies for safety and capacity enhancements in the terminal area. Specific projects have included windshear detection and alerting, integration of aircraft Flight Management Systems with ground-based controller tools, development of a terminal-area approach spacing concept, and development of low-noise flight procedures.

Mr. Terence Abbott recently retired as a Senior Research Engineer at the NASA Langley Research Center in Hampton, Virginia. He has conducted research in display format design for all-weather helicopter operations, airborne concepts for increasing airport capacity, head-up display formats for reduced in-trail separation via wake vortex avoidance, design guidelines for moving-tape formats on primary flight displays, and the development of task-oriented display design concepts. He has authored over 40 technical papers relating to flight deck interface issues. He was a recipient of a *Research and Development Magazine* R&D-100 Award and the NASA Medal for Exceptional Engineering Achievement.

Mr. William R. Capron holds BS and MS degrees in Aerospace Engineering from the University of Kansas. He has participated in the development of various simulation and in-flight air-traffic capacity and safety research projects at the NASA Langley Research Center since 1971. Notable projects include the Evaluation of Microwave Landing System (MLS) Effect on the Delivery Performance of a Fixed-Path Metering and Spacing System; Final-Approach Spacing Aids (FASA) Evaluation for Terminal-Area, Time-Based Air Traffic Control; Airborne Information for Lateral Spacing (AILS); Concept of Operations for Commercial and Business Aircraft Synthetic Vision Systems; and the Advanced Terminal Area Approach Spacing (ATAAS) research activities.